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**A method comparison study of invasive blood pressure and noninvasive blood pressure  
measurement in isoflurane-anaesthetized horses performed with Cardiocap<sup>TM</sup> and the  
oscillometric device Sentinel**

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**A method comparison study of invasive blood pressure and noninvasive blood pressure measurement in isoflurane-anaesthetized horses performed with Cardiocap<sup>TM</sup> and the oscillometric device Sentinel**

**Abstract**

**Objective:** To assess the accuracy of the noninvasive blood pressure (NIBP) measured by the oscillometric device Sentinel compared to the invasive blood pressure (IBP) measured by Cardiocap in anaesthetized horses undergoing surgery. To assess if differences between the Sentinel and Cardiocap are associated with recumbency, cuff placement, weight of the horse or acepromazine premedication and to describe the usefulness of Sentinel.

**Study design:** Prospective method comparison study.

**Animals:** Twenty-nine horses.

**Methods:** IBP was measured via a catheter in the facial artery, transverse facial artery or metatarsal artery. NIBP was measured using cuffs of appropriate size placed on the cannon bones or on the tail in random order to detect SAP, MAP, DAP and HR.

**Results:** Sentinel yielded generally higher measurements than Cardiocap. Accuracy of Sentinel was found to vary with recumbency and position of the cuff. No significant difference between Cardiocap and Sentinel due to weight of the horse or acepromazine premedication was found.

**Conclusion and clinical relevance:** Despite a higher variability of Sentinel compared to Cardiocap, NIBP measurements are an appropriate alternative to measure blood pressure under field conditions.

**Keywords:** blood pressure, horse, anaesthesia

**Studie zum Vergleich des mittels Cardiocap™ invasiv gemessenen Blutdruckes mit dem mittels Sentinel nicht invasiv gemessenen Blutdruckes bei Pferden unter Isoflurananästhesie**

**Zusammenfassung**

**Ziele:** Beurteilung der Genauigkeit des nicht invasiven Blutdruckes (NIBP) gemessen mit dem oszillometrischen Monitor Sentinel im Vergleich zum invasiven Blutdruck (IBP) gemessen mit Cardiocap bei Pferden in Anästhesie. Zu untersuchen, ob Unterschiede zwischen Sentinel und Cardiocap assoziiert sind mit der Lage bzw dem Gewicht der Pferde, der Position der Blutdruckmanschetten oder Azepromazin Prämedikation.

**Studiendesign:** Prospektive Studie

**Tiere:** 29 Pferde

**Methoden:** IBP wurde via Katheter in der Facial-, Transversal- oder Metatarsalarterie gemessen. NIBP wurde mittels passender Blutdruckmanschetten über den Röhrebeinen oder dem Schweif erfasst. Ein gemischtes Model verglich die Blutdruckwerte des IPB und NIBP und schätzte den Einfluss von Position des arteriellen Katheters, Platzierung der Blutdruckmanschetten und die Kombination von Lage, Gewicht des Pferdes oder Azepromazin Prämedikation ein.

**Resultate:** Sentinel tendierte zu höheren Messungen als der Cardiocap. Die Genauigkeit von Sentinel variierte mit der Lage der Pferde und der Position der Blutdruckmanschetten.

**Klinische Relevanz:** Obwohl Sentinel eine höhere Variabilität zeigte im Vergleich zum Cardiocap, ist die NIBP Messmethode eine angemessene Alternative um den Blutdruck unter Feldbedingungen zu messen.

**Stichwörter:** Blutdruck, Pferd, Anästhesie

**A method comparison study of invasive blood pressure and noninvasive blood pressure measurement in isoflurane-anaesthetized horses performed with Cardiocap<sup>TM</sup> and the oscillometric device Sentinel**

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## **Abstract**

### **Objective**

To assess the accuracy of the noninvasive blood pressure (NIBP) measured by the oscillometric device Sentinel compared to the invasive blood pressure (IBP) measured by Cardiocap in medetomidine-isoflurane-anaesthetized horses undergoing surgery. To assess if differences between the Sentinel and Cardiocap are associated with recumbency, cuff placement, weight of the horse or acepromazine premedication and to describe the usefulness of Sentinel.

### **Study design**

Prospective method comparison study in horses under general anaesthesia with replicates of simultaneous NIBP measurements and the standard IBP measurements.

### **Animals**

Twenty-nine horses.

### **Methods**

IBP was measured via a catheter in the facial artery, transverse facial artery or metatarsal artery. Invasive systolic (SAP), mean (MAP), and diastolic (DAP) arterial blood pressures as well as heart rates (HR) were recorded. NIBP was measured using cuffs of appropriate size placed on one of four cannon bones or on the tail in random order to detect SAP, MAP, DAP and HR. A mixed effects model approach compared the IBP to the NIBP values and assessed potential effects of catheter placement, localisation of the cuffs and in combination with recumbency, weight of the horse or acepromazine premedication.

## **Results**

Sentinel yielded generally higher measurements than Cardiocap. Accuracy of Sentinel was found to vary with recumbency and position of the cuff. Estimated mean differences between the two methods decreased from SAP in lateral recumbency (range -5.3 to -56.0 mmHg) and in dorsal recumbency (range 0.8 to -20.7 mmHg), to MAP in lateral recumbency (range -1.8 to -19.0 mmHg) and in dorsal recumbency (range 13.9 to -16.4 mmHg) to DAP in lateral recumbency (range 0.5 to -6.6 mmHg) and in dorsal recumbency (range 21.0 to -15.5 mmHg). The NIBP measurement was about 2 times more variable than the IBP measurement. No significant difference between Cardiocap and Sentinel due to weight of the horse or acepromazine premedication was found. In 227 of 1047 (21.7%) measurements Sentinel did not deliver a result.

## **Conclusion and clinical relevance**

Despite a higher variability of Sentinel compared to Cardiocap, NIBP measurements are an appropriate alternative to measure blood pressure under field conditions.

*Keywords: invasive blood pressure monitoring, non-invasive blood pressure monitoring, Sentinel, horses, anaesthesia*

## **Introduction**

General anaesthesia in horses is associated with a significantly higher perioperative mortality rate (Wagner 2009) than reported for other species. Depending on the study design perioperative mortality rate in horses varies from 0.63-13.7% (Mee et al. 1998; Johnston et al. 2002; Senior et al. 2007). About a third of such fatalities are directly related to cardiovascular problems during anaesthesia and about another third are a result of poor performance in recovery, certainly often also related to poor cardiovascular performance and thus inadequate perfusion of muscles during anaesthesia.

Horses are very sensitive to the cardiovascular depressant effects of inhaled anaesthetics (Muir et al. 1983; Wagner & Brodbelt 1997; Rasis et al. 2005). Hypotension leads to poor tissue perfusion and oxygenation, in horses often leading to postanaesthetic myopathy and problems in recovery (Riebold & Evans 1985; Keegan & Greene 1994). To prevent post-anaesthetic myopathy, MAP should be maintained  $> 70$  mmHg (Duke et al. 2006).

Therefore to optimize anaesthetic management, measurement of systemic arterial BP is an important part of monitoring anesthetized horses (Riebold & Evans 1985). Direct intraarterial BP measurement in horses is the accepted gold-standard or reference method for determining SAP, MAP and DAP (Shih et al. 2010). This is invasive, relatively expensive and under field conditions not practicable. NIBP measurement is not commonly used, because so far only few suitable and accurate devices for horses exist.

An accurate NIBP device would simplify the measurement of arterial blood pressure and might become wide spread and thus would improve anaesthetic management of equidae.

The aim of this method comparison study was to assess the accuracy of the NIBP device Sentinel in comparison to the IBP measurements obtained by Cardiocap under clinical conditions and to assess if potential differences between the two methods are associated



with recumbency and cuff placements, acepromazine premedication and weight of the horse.

## **Materials and methods**

### **Study design**

Prospective method comparison study in horses under general anaesthesia with replicates of simultaneous NIBP measurements and the standard IBP measurements.

### **Animals**

Twenty-nine client-owned horses with a body weight ranging between 56 and 650 kg body weight (mean  $394.3 \pm \text{SD } 49.5$  kg) were included in the study. Twenty-six horses with ASA status I or II underwent elective surgical procedures and 3 cases were colic horses (ASA IV). The 29 horses consisted of nineteen male and ten female with a mean age of 7.6 years ( $\pm \text{SD } 4.9$  years, range 0.1-20 years). All breeds are listed in Table 1.

### **Study protocol**

In the adult elective cases food but not water was withheld for 9 to 12 hours, in foals 1-4 hours. A 14-gauge/2.0 x 160 mm catheter (Secalon-T<sup>TM</sup>, Becton Dickinson AG, Basel, Switzerland) was placed into the jugular vein of either side under local anaesthesia. The horses were premedicated with intravenous (IV) flunixin (Flunixin ad us. vet.; Biokema SA, Crissier, Switzerland)  $1 \text{ mgkg}^{-1}$  for soft tissue surgery or IV phenylbutazone (Phénylarthrite injectable; Vetoquinol, Lure, France)  $4 \text{ mgkg}^{-1}$  for orthopaedic surgery. Half an hour to one hour before anaesthesia induction some horses received acepromazine

(Prequillan; Provect AG, Switzerland),  $0.03 \text{ mgkg}^{-1}$  intramuscularly (IM).

Immediately before induction of anaesthesia, horses were sedated with medetomidine (Dorbene, Graeb AG, Bern, Switzerland)  $7 \text{ } \mu\text{gkg}^{-1}$  IV. Two horses were sedated with romifidine (Sedivet, Boehringer Ingelheim, Basel, Switzerland)  $100 \text{ } \mu\text{gkg}^{-1}$  instead. Romifidine balanced anaesthesia was tested for another study in comparison to medetomidine balanced anaesthesia. As soon as the horses were sedated, anaesthesia was induced with ketamine (Narketan 10 ad us. vet.; Vetoquinol, Ittigen Bern, Switzerland)  $2.2 \text{ mgkg}^{-1}$  IV and diazepam (Valium 10 mg; Roche Pharma Schweiz AG, Reinach, Switzerland)  $0.02 \text{ mgkg}^{-1}$  IV. Once the horses were recumbent, the trachea was intubated and they were hoisted onto an inflatable mattress on a surgical table. There the horses were connected immediately to a large animal anaesthesia machine via a large animal circle system. Most of the horses breathed spontaneously. When indicated, the lungs were mechanically ventilated. Maintenance of anaesthesia was with isoflurane and a CRI of medetomidine  $3.5 \text{ } \mu\text{gkg}^{-1}\text{hr}^{-1}$  (or romifidine  $30 \text{ } \mu\text{gkg}^{-1}\text{hr}^{-1}$  in the romifidine premedicated horses) was administered by an infusion pump (Phoenix, Schoch Electronics AG, Regensdorf-Zürich, Switzerland). Ringer's Lactate (Ringer-Laktat-Lösung, Fresenius Kabi AG, Stans, Switzerland) was infused ( $5\text{-}10 \text{ mlkg}^{-1}\text{hr}^{-1}$ ). Dobutamine up to  $1.25 \text{ } \mu\text{gkg}^{-1}\text{min}^{-1}$  (Dobutrex; Teva Pharma AG, Aesch, Switzerland) was administered to maintain MAP above 70 mmHg.

IBP was measured via a 22-gauge catheter (Surflo IV Catheter 22G x 1"; Terumo, Leuven, Belgium) inserted into the facial artery, the transverse facial artery or the metatarsal artery. Location depended on the surgical approach. The arterial catheter was attached to a pressure transducer (Pressure Transducer DTX/Plus<sup>Tm</sup>; Beton Dickinson AG; Allschwil, Switzerland) through a saline-filled non-expandable line (Syramed line, Arcomed AG,

Switzerland), positioned and zeroed at the level of the heart. The catheter was flushed with pressurized saline continuously. The transducer was connected to a multiparameter monitor (Cardiicap 5; Anandic, Medical System AG, Diessenhofen, Switzerland). A lead II ECG was displayed, and HR was obtained from this lead.

The NIBP was measured by the oscillometric machine Sentinel (Sentinel Veterinary Bloodpressure Monitoring, Vetronics, Torquay, United Kingdom) via an appropriate sized cuff. The cuff automatically inflates to a pressure above systolic pressure to stop the blood flow. Then the cuff is deflated at a set rate of  $3 \text{ mmHgsec}^{-1}$  until the presence of pulse pressure is detected. The amplitude of the pulse waveforms is measured and taken as systolic pressure. Cuff deflation continues until no further pulse waveforms are detected. This value is the diastolic pressure. The MAP is obtained by extrapolation the regressed line of the systolic and diastolic values. The standard formula to calculate MAP in veterinary and human medicine is  $(\text{MAP} = \text{DAP} + (1/3(\text{SAP} - \text{DAP}))$  (Kittleson & Olivier 1983; Kiers et al. 2008).

After the arterial catheter was inserted into one artery, the circumference of the metacarpus, metatarsus and the tail was measured. Guidelines used to chose the cuffs are given in Table 2. According to Sawyer (Sawyer et al 1991) we calculated 40 and 60% of the circumference of the leg and tail, respectively and the arithmetic mean of these two values was judged ideal. Depending on the surgical approach, the cuffs were attached to all four cannon bones and to the tail. The order of the cuff site in each horse was randomised. The cuffs were placed on the metacarpus over the A. digitalis palmaris communis II, on the metatarsus over the A. metatarsa dorsalis III or on the tail over the A. caudalis coccygea mediana. The Sentinel was always positioned at the same level as the transducer used for IBP measurement. As soon as all the cuffs were in place, the measurements were started.

The cuff inflation and deflation lasted 30 to 60 seconds. The corresponding IBP readings were recorded simultaneously. The display of the Sentinel was showing the SAP, MAP, DAP and HR. NIBP measurement readings were taken four times in series and then the next cuff position NIBP was measured another four times. The sequence of the measurement position was in each horse randomized. If the cuffs on every leg and tail were inflated four times the reading cycle started again. This procedure was continued until the end of anaesthesia.

Half an hour before the end of anaesthesia, morphine (Morphine HCl 10 mg; Sintetica SA, Mendrisio, Switzerland)  $0.1 \text{ mgkg}^{-1}$ ) was administered IM. At the end of anaesthesia, the horses were transported to a padded recovery box. For recovery, all the horses were sedated with IV medetomidine  $2 \text{ } \mu\text{gkg}^{-1}$  except two horses that got romifidine before were sedated with IV romifidine  $10 \text{ } \mu\text{gkg}^{-1}$ . Oxygen was insufflated ( $10 \text{ Lmin}^{-1}$ ) through the endotracheal tube. The trachea was extubated when the horses regained their swallow reflex. Horses were allowed to recover without assistance except four foals and one pony.

### **Statistical analyses**

The aim of the statistical analysis was to estimate a potential difference (bias) between Sentinel and Cardiocap measurements, to assess if both methods display significantly different variances and to assess if measurement differences are significantly associated with cuff placement on one of the four legs or the tail in combination with right lateral, left lateral or dorsal recumbency (in total 15 possible combinations of cuff placement and recumbency), with body weight of the horse or with acepromazine premedication. As outcome variables, either the difference between Sentinel and Cardiocap at each measurement for SAP, DAP, MAP and HF (i) or the measurements of both methods for

SAP, DAP, MAP and HF (ii) were analyzed. For i and ii, in order to account for potential clustering within animal, time and horse were included as random effects (random slope and intercept). In i, the combination of cuff placement and recumbency, weight and acepromazine premedication were included in the model as fixed effects. In ii, in addition to the three fixed effects used in i, the measurement method, an interaction term between combination of cuff placement/recumbency and method as well as the anatomical location of the artery used for the IBP measurements (A. facialis and A. facialis transversa were summarized in “head” artery and A. metatarsa dorsalis III as “leg” artery) were included as fixed effects. Restricted maximum likelihood estimation (REML) was used to find the appropriate random structure, maximum likelihood estimation (ML) was used to assess the significance of the fixed effects. Model selection was based on Akaike’s information criterion (AIC) with lower values indicating a better model fit. Model validation was performed by visual checking the residuals for homogeneity and independence. Results of the linear mixed effects models are reported as estimated marginal means and their corresponding 95% confidence intervals.

Statistical analysis was performed using software R version 2.14.0 (R Development Core Team, 2012) and the package nlme (Pinheiro 2011).

## **Results**

In this study, a total of 1047 NIBP measurements from 29 horses were evaluated. 820 (78.3%) of these 1047 measurements were without an error message on the monitor of the Sentinel, and therefore used for statistical comparisons. In general, measurements with the Sentinel showed higher BP values than the values from Cardiocap and the NIBP values

were more variable. Error messages displayed by Sentinel were the following: artefact, inflated time out, inflated timeout air leak, measurement timeout or weak or no signal. The mean cuff sizes we used, in percentage of the circumference of the positions where they were fixed, were the following: on the frontlimb 49.36%, on the tail 50.76% and on the metatarsus 49.84% respectively.

The results of statistical analysis are given in estimated marginal means (Table 3). Confidence intervals (95%) are provided to quantify sampling variability in the experiment (i.e. what values would we expect to occur if the measurements were taken from another random sample of comparable animals). The detailed results of the statistical models are given for SAP, MAP, DAP and HF in Table 3 separately for the cuff placement and left or right lateral recumbency and dorsal recumbency. The estimated difference between IBP and NIBP for e.g. SAP if the cuff was placed at the left hindlimb and the animal positioned in left lateral recumbency was -23.0 mmHg with a 95% confidence interval between -9.9 and -36.1 mmHg. The interaction between the measurement method and the combination of cuff placement and recumbency was highly significant ( $p < 0.0001$ ).

In general, if the animal was in lateral recumbency for SAP, MAP and DAP, the lowest difference between the two measurements were obtained if the cuff was placed at the tail. Whereas for animals in dorsal recumbency the lowest difference between the two methods was determined for the cuffs fixed over the cannon bones.

If the horse was placed in lateral recumbency, most of the NIBP overestimated BP therefore most of the values of the difference between the two measurements are negative. Horses in dorsal recumbency always showed an overestimation of the BP if the cuff was on the tail. If the cuffs were on the limbs in horses in dorsal recumbency half of the BP values were underestimated.

For SAP, the difference between the two methods was also significantly influenced by the placement of the arterial catheter to measure IBP. Measurement of systolic IBP in A. facialis yielded 9.2 mmHg higher values compared to A. metatarsalis.

Weight had no effect on NIBP reading (SAP  $p = 0.554$ , MAP  $p = 0.725$ , DAP  $p = 0.797$ ).

There was no effect of acepromazine on the NIBP reading (SAP  $p = 0.740$ , MAP  $p = 0.602$ , DAP  $p = 0.651$ ).

In terms of quality criterion, it was tested if exclusion of all Sentinel HR values (and the corresponding SAP, MAP and DAP values from the same measurement point) which differed more than 15 % from the effective HR (55 measurement points) influenced the results of the analysis concerning accuracy of NIBP measurements, which was not the case.

## **Discussion**

This study compared NIBP measurements by Sentinel with the intraarterial bloodpressure measurements by Cardiacap taking into consideration the recumbency of the horse and the cuff placement, the placement of the arterial line and the influences of weight and acepromazine premedication on BP reading.

In general there was a significant difference between the two measurement methods. The accuracy of Sentinel was found to vary with recumbency and position of the cuff.

If the horses were in dorsal recumbency, the most accurate NIBP measurements were derived from the cuffs placed over the cannon bones and in lateral recumbency over the tail artery. In lateral recumbency, the tail is more or less on the same height level as the heart and therefore the transducer and the cuff are on the same level, and in dorsal recumbency the cannon bones are also more levelled with the heart (and transducer) than the tail. It has

been previously shown, that noninvasive BP values obtained in standing horses need to be corrected to the level of the heart (Gay et al. 1977). Other investigators demonstrated that 7.0 mmHg have to be added to both systolic and diastolic values for every 10 cm of distance between a horizontal line drawn through the point of the shoulder and a horizontal line drawn through the tail at the position of cuff placement (Gay et al. 1997; Wagner & Brodbelt 1997). As the present study aimed at comparing the NIBP measurement to the clinical standard measurement of arterial blood pressure we did not assess the difference of the height between the transducer for IBP and the cuff. If we presume that in dorsal recumbency between the cuff on the leg and the transducer there was an average difference of 30 cm height the 21 mmHg pressure difference resulting from that would at least partly explain why NIBP measurements were nearly always higher than IBP.

An important factor influencing accuracy of NIBP measurement is the width of the cuff relative to the size of the leg or tail (Taylor 1981). If the cuff is too narrow, the BP will be overestimated. In contrast, if the cuff is too wide, the BP will be underestimated (Riebold & Evans 1985). The cuff size used in the present study was 40 to 60% of the circumference of the leg or tail (resulting in a mean cuff size of 49.36% - 50.76%), a value commonly recommended in text books and the manufacturers of NIBP devices. In the horse literature the recommendations for optimal cuff size vary, but mostly smaller cuffs are recommended. Muir et al. (1983) demonstrated that the ideal cuff size is 35% of the circumference of the tail and another study in laboratory ponies with clipped tail recommended even a cuff width of only 25% of the circumference of the tail (Geddes et al. 1977). To measure the NIBP in foals with a sphygmomanometer over the forearm, other authors took 45% of the circumference of the forearm to calculate the cuff size (Franco et al. 1986). Bailey et al. (1994) chose a cuff width of 40% of the circumference of the tail and other investigators



found that 33.9% of the circumference of the tail was the optimal size for the NIBP measurement of the systolic pressure (Parry et al. 1982). As the cuffs used in the present study were on average about 50% of the circumference of leg or tail (so wider than the average recommendation in the horse literature) this does not explain, why pressures displayed by NIBP were nearly almost always higher than the ones displayed by IBP.

It is known, that the arterial pulse is amplified as it moves toward the periphery due to wave reflection and the arterial tree. This amplification is characterized by an increased systolic BP (Muir et al. 1983; Bedford & Shah 1995) and might partly explain the influence of position of the intraarterial catheter (eg. leg or facial artery) on the invasive blood pressure measurements in the present study.

In our study SAP values differed most between the measurement methods and the DAP readings least - MAP was in between. Other authors that studied foals reported that NIBP measurements agreed most closely with IBP measurements for MAP (Nout et al. 2002). For the routine use of an oscillometric NIBP measurement device in horses, the MAP is clinically probably more relevant than the systolic or diastolic measurements displayed, as  $MAP < 60-70 \text{ mmHg}$  is considered the critical value that needs intervention to prevent the formation of myopathy. With the optimal cuff position the values obtained in the present report were within clinically acceptable accuracy ranges.

In dogs a major increase in systolic pressure was shown when peripheral vasoconstriction such as in heart failure or hypovolemic shock was present (Kittleson and Olivier 1983). In our study we don't know if vasoconstriction influenced our measurements as we did not measure cardiac output. However acepromazine, a potent vasodilator that certainly reduces peripheral vasoconstriction, did not influence the measurements.

Previous research has demonstrated that the most important factor affecting the accuracy of

an indirect BP measurement device is the pulse detection (Grosenbaugh & Muir 1998). Sawyer et al. (1991) recognized that one method of checking reliability of IBP measurement is to ensure, that the indirect pulse rate displayed correlates with pulse rate palpated manually. We found that Sentinel detected the HR accurately. HR according to Sentinel was only 1.16 times more variable than the effective HR measured via ECG. The variability of NIBP however was two times the variability of IPB. When we excluded all the blood pressure measurements from time points with heart rates with more than 15% deviation (55 data points) from the effective HRs (820 data points), NIBPs did not agree better with IBPs.

In 21.7% of all measurements with Sentinel, no value for arterial blood pressures was obtained, but different error messages were displayed. The display showed “artefact”, when the limbs were moving because of surgical manipulation or breathing. When NIBP was measured with the Dinamap oscillometric device, most of the artefacts were also produced by movement (Kittleson & Olivier 1983). The other failure indications of Sentinel (“inflated timeout”, “inflated timeout air leak”, “measurement timeout”, “weak or no signal”) were related to non-detection of the pulse. Peripheral vasoconstriction and low cardiac output have been shown in dogs to cause a loss of signal (Dyson 1997). In the horses in our study we did neither assess peripheral vascular resistance nor cardiac output, but it is well known that individual horses under general anaesthesia show reduced cardiac output. Further alpha2-agonists, such as medetomidine used in the present study, induce vasoconstriction to different extents. Also thick hair at the measurement site has been reported to cause measurement failures with other NIBP devices (Kittleson & Olivier 1983) whereas others showed no difference when cats legs or horses tails were clipped for NIBP measurements (Parry et al. 1982; Branson et al. 1997).

The accepted gold standard for intraoperative assessment of arterial BP is the direct intra-arterial BP measurement, even though it is technically demanding and potentially leads to complications (Wernick et al. 2010). Oscillometric measurement of NIBP on the other hand is non-invasive, technically simple and bears no risk of infection.

In conclusion, we found that the oscillometric device Sentinel under clinical circumstances displays mean arterial blood pressures within acceptable accuracy limits to help guide management of fluid therapy and use of vasopressors. We recommend to place the cuff on the tail in horses that are operated in lateral recumbency and on the metatarsal or metacarpal bone in patients in dorsal recumbency.

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Table 1: Patient demographics

Breeds represented	Warmbloods (11), Thoroughbreds (4), iceland horse (3), Freiburger (3), Ponies (2), Shetland (1), Tinker (1), Shire (1), Quarter horse (1), Paint horse (1), Arabian (1)
Age (years)	7.6 ( $\pm$ SD 4.9, range 0.1-20)
Gender (m/f)	19/10
Body weight (kg)	394.3 ( $\pm$ SD 49.5, range 56-650)
Recumbency (dorsal/lateral)	16/13
Duration of Anesthesia (minutes)	136.4 ( $\pm$ SD 22.6, range 55-210)
Acepromazine/No acepromazine	20/9
Medetomidine/Romifidine	27/2

Table 2. Guidelines to chose the appropriate size of the cuffs

Cuff number	Circumference leg/tail (cm)	Cuff width (cm)
1	5.0-11.5	5.5
2	12.0-14.0	6.5
3	14.5-17.0	8.0
4	17.5-21.0	9.5
5	21.5-26.0	12.0
6	26.5-29.0	14.5
7	29.5-33.0	15.0



Table 3: Results from the linear mixed effect model for estimated mean differences between NIBP and IBP measurements in mmHg depending on cuff position and recumbency.

		estimated mean effects and confidence intervals (95%)		
		horse position		
BP	cuff position	left lateral recumbency	right lateral recumbency	Dorsal recumbency
SAP	left metatarsus	- 23.0 (-9.9; -36.1 )	- 24.7 (-6.7; -42.7)	- 2.2 (14.1; -18.5)
	right metatarsus	- 28.3 (-17.3; -39.3)	- 56.0 (-37.8; -74.2)	- 1.5 (14.2; -17.2)
	tail	- 14.3 (-5.3; -23.3)	- 5.3 (11.6; -22.1)	- 20.7 (-5.4; -36.0)
	left metacarpus	- 16.6 (-6.6; -26.6)	- 27.9 (-10.7; -45.1)	+ 0.8 (16.3; -14.7)
	right metacarpus	- 36.2 (-25.6; - 46.8)	- 23.3 (-5.9; -40.7)	- 1.7 (13.6; -17.0)
MAP	left metatarsus	- 10.3 (-0.1; -20.5)	- 6.0 (8.1; -20.1)	+ 11.8 (24.3; -0.7)
	right metatarsus	- 11.7 (-3.9; -19.5)	- 19.0 (-4.9; -33.1)	+13.9 (26.2; 1.6)
	tail	- 6.2 (0.3; -12.7)	- 1.8 (11.5; -15.1)	- 16.4 (-4.4; -28.4)
	left metacarpus	- 7.5 (-0.4; -14.6)	- 10.0 (3.7; -23.7)	+ 11.1 (23.3; -1.1)
	right metacarpus	- 14.1 (-6.7; -21.5)	- 7.7 (6.0; -21.4)	+ 10.8 (22.8; -1.2)
DAP	left metatarsus	- 5.0 (5.0; -15.0)	+ 0.5 (14.4; -13.4)	+ 17.9 (30.2; 5.6)
	right metatarsus	- 4.5 (3.1; -12.1)	- 2.7 (11.0; -16.4)	+ 21.0 (33.0; 9.0)
	tail	- 2.9 (3.4; -9.2)	- 2.4 (10.5; -15.3)	- 15.5 (-3.7; -27.3)
	left metacarpus	- 6.6 (0.3; -13.5)	- 3.0 (10.3; -16.3)	+ 15.5 (27.3; 3.7)
	right metacarpus	- 5.3 (2.0; -12.6)	- 3.3 (10.2; -16.8)	+ 16.7 (28.5; 4.9)
HF	left metatarsus	- 0.9 (0.9;-2.7)	- 2.5 (-0.1; -4.9)	- 2.0 (0.2; -4.2)

	right metatarsus	- 2.1 (0.1; -4.3)	- 1.0 (1.4; -3.4)	- 2.3 (-0.3; -4.3)
	tail	- 1.8 (0.2; -3.8)	- 3.3 (-1.3; -5.3)	- 2.7 (0.7;-4.7)
	left metacarpus	- 0.2 (1.8; -2.2)	- 5.1 (-2.9; -7.3)	- 2.3 (-0.3; -4.3)
	right metacarpus	-3.0 (-0.8; -5.2)	- 3.3 (-1.1; -5.5)	- 2.6 (-0.6; -4.6)

The estimated difference between IBP and NIBP for e.g. SAP if the cuff is placed at the left hindlimb and the animal positioned in left lateral recumbency was -23.0 mmHg with a 95% confidence interval between -9.9 and -36.1 mmHg.

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